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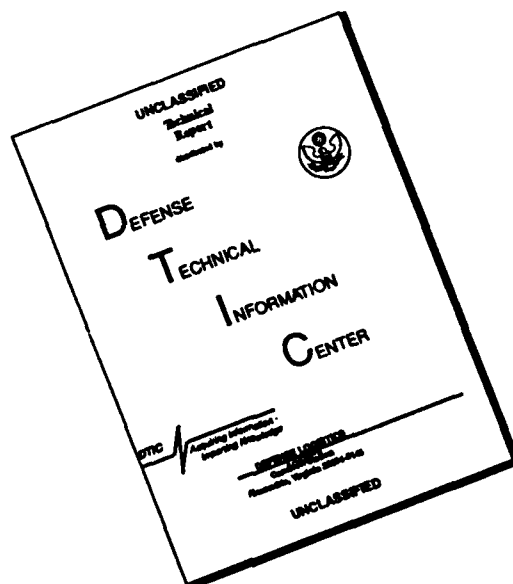
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## Chapter 14

### Polarization Diversity in Radar Meteorology: Early Developments

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#### 1 INTRODUCTION

Polarization is a fundamental descriptor of electromagnetic waves and, as such, has received the attention of scientists for over three centuries, beginning with the discovery of double refraction in crystals by Bartolinus and the discovery of polarized light by Huygens in the seventeenth century. Dramatic advances in the understanding of optics and electricity occurred thereafter, particularly throughout the nineteenth century, culminating in Maxwell's classic formulation of the electromagnetic theory, Hertz' extensive experiments on radiation fields, and Lord Rayleigh's investigations in electromagnetic scattering. These laid the groundwork for the development of radio, radar, and all that was to come in telecommunications during the twentieth century.

The importance of polarimetry in radar was immediately evident with the first use of pulse methods to probe the ionosphere by Breit and Tuve (1926). These experiments not only were the forerunner of the major radar developments that began prior to World War II, but also led to important breakthroughs in plasma physics by stimulating the development of the theory needed to explain the doubly refracting nature of the ionosphere. Thus, radar polarimetry was an essential component of the very first radar.

As radar evolved during the war, atmospheric effects were recognized as fundamentally important, since departures from free space propagation and interference from precipitation were often observed (Ridenour, 1947). The latter effects led to the use of radar for observing and tracking storms, followed by an extended history of research and deployment of operational radars throughout the world. Circular polarization was found to be particularly relevant to the radar clutter problem of detecting targets in the presence of rainfall as illustrated by White (1954). The significance of polarization was evident from

the early stages of research, but little attention, compared to other radar opportunities, was given to the phenomenon through the 1960s, except at select organizations and often for short periods of time. Many of the ideas that have proven useful today for precipitation characterization were considered during this period, although a number of very important insights reside outside the peer-reviewed literature. This chapter focuses on these contributions and examines several important cases. The complete story may never be known, but the roles of the state of technology, institutional priorities, individual interests, and the availability of resources, among other factors, clearly were important in the development of the field.

#### 2 CONCEPTS OF WAVE POLARIZATION

The general form of an electromagnetic wave can be described as an elliptically polarized wave where the  $E$ -field rotates at a rate  $\omega$  in either a clockwise or counterclockwise direction (Beckmann, 1968). This may be expressed mathematically in a number of ways, and given in terms of two linear components or two circular components, or any two orthogonal components. In general three independent parameters are needed to describe the state of polarization of a monochromatic vector wave field. For example, the amplitudes  $E_1$ ,  $E_2$  and the relative phase between these two orthogonal linear component waves, or the amplitudes  $E$ , and  $E_i$  and the relative phase between these two counterrotating circularly polarized waves, can be used for this purpose.

Poincaré (1892) introduced a spherical visualization of the different states of polarization where the equator represents linear polarization, the North Pole corresponds to right-hand circular polarization and the South Pole to left-hand circular polarization. The Stokes (1852) parameters are simply the Cartesian coordinates of the points on the sphere or, alternatively, of the parameters of the polarization ellipse. The Stokes parameters are readily related to observable quantities, expressed as a combination of either

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linearly or circularly polarized components. Another important representation is the coherency matrix,  $J$ , which describes a set of four intensities that are directly related to the Stokes parameters. Unpolarized, fully polarized monochromatic, and the superposition of waves may all be described by this matrix.

In addition to the polarimetric description of waves, the relationship between the incident wave and response of the target to the electromagnetic excitation must be described. This is usually done through the scattering matrix representation, which relates the scattered wave fields to the incident wave fields (Sinclair, 1950). This transformation is a fundamental descriptor of the scattering process in that it completely defines the polarimetric properties of a radar target. Although the literature is replete with major works on electromagnetic scattering, the contribution of van de Hulst (1957) clearly stands out as having greatly influenced the development of radar meteorology, including polarimetry. This monograph presents a thorough review of basic theory, including concepts of scattering, absorption, wave propagation in vacuum and in particle-filled media, polarized light, and an examination of particles of various forms.

Giuli (1986) gave an excellent, comprehensive review of the role of dual polarization in radar. He traced the major developments and cited the contributions that have made polarization an important feature in radar. In addition, Boerner et al. (1981) developed a substantial and valuable bibliography on polarimetry; it contains significant monograph works as well as many citations of individual contributions and references to unpublished work. More specific to the subject of this chapter is a report by Metcalf et al. (1977), which reviewed polarization radar and lidar technology in meteorology research.

### 3 EARLY ACTIVITIES IN POLARIZATION RESEARCH IN THE UNITED STATES

In the United States, radar polarimetry followed the path of theory, equipment, and observations and applications, but with two different approaches. One was directed toward the use of circular polarization and the other toward the use of linear polarization.

Atlas (1951) gave a qualitative description of Gans's theory of scattering from ellipsoidal bodies and from this derived the dependence of scattering intensity with the axial ratio of randomly oriented, oblate and prolate water and ice spheroids at 1.25, 3.2 and 10-cm wavelengths. These results illustrated that there could be a very strong dependence on shape of the scattering intensity and that the amount of depolarization was less for low density snow and ice particles than for oblate water drops. Interestingly, Atlas' plots of the variation of the copolar scattered intensity from horizontally oriented oblate particles contained

the concepts envisioned by Seliga and Bringi (1976) with differential reflectivity, given that the axial ratio of hydrometeors are size dependent according to the results of Pruppacher and Pitter (1971; preceded by earlier works on drop shapes by Spilhaus, 1948; Jones and Dean, 1953; Magono, 1954; Jones, 1959). Atlas's major conclusions, aside from the intrinsic information in the computations of scattering from various types of hydrometeors, were that the scattering dependence of shape and alignment of hydrometeors, including sensitivity to polarization, should have important ramifications for the interpretation of the bright band.

Atlas et al. (1953) and Stevenson (1953), the latter of whom extended Gans's theory to larger size scatterers, used scattering computations to demonstrate the utility of circular depolarization ratio (CDR) and linear depolarization ratio (LDR) radars for investigating microphysical shape effects; these greatly influenced the design of the polarization diversity radars developed by the National Research Council of Canada in the late 1960s. Additional understanding of the polarimetric properties of hydrometeors resulted from experimental backscattering studies of ice models by Harper (1962) in the United Kingdom, Atlas and Wexler (1963) in the United States, and from the theoretical and computational efforts of Oguchi (1960, 1964, 1966) in Japan, whose work focused on problems related to the propagation of radio waves through storms. The latter subject has had an enormous influence on radar polarimetry, and comprehensive references to this large body of knowledge may be found in reviews by Hogg and Chu (1975) and Oguchi (1984).

Concurrent with the work directed specifically to meteorology, very important studies were carried out at the Ohio State University (OSU) by Prof. Edward Kennaugh on contract to the Air Force between 1949 and 1957. The reports of this work were compiled in a set of commemorative volumes by Moffatt and Garbacz (1984). These reports focused on the polarization characteristics of various targets, including rain, and were motivated in part by the need to understand the effects of rainfall on target detection. Kennaugh's studies were both theoretical and experimental, and examined a number of fundamental polarization concepts related to radar. Examples of these are the use of the target scattering matrix and polarization sphere; generalized echo area; optimum polarization; polarization diversity; and polarization properties of rainfall. Now that Kennaugh's work has been more widely publicized, it is certain to impact greatly the future development of polarimetry in radar meteorology.

Among the early meteorological observations using polarization techniques were those carried out at the Massachusetts Institute of Technology (MIT). Newell et al. (1955, 1957) proposed using the scattering properties of ellipsoidal hydrometeors and their response to circularly polarized waves to determine a measure of the "roundness" of the scatterers. Since their antenna was unable to

receive both circular components simultaneously, they chose to utilize the ratio of the respective powers received in the channel of transmission due to transmitted waves of linear and circular polarization. They called this "cancellation" and noted that this ratio may be sensitive to the orientation. Their radar system exhibited a cancellation limit of  $-19$  dB operated at 3 cm with a 2 deg beamwidth and 40 kW peak power. Their results were represented in histograms deduced from 1347 observations showing cancellation responses in snow, the melting layer, and rain, as well as histograms for summer showers that show the great difference between the melting layer and rain. They interpreted the cancellation measurements in terms of the axial ratios of equivalent ellipsoids, assuming the ellipsoids are randomly oriented, of the same phase state, and with the same axial ratios. Similar measurements of the melting layer were made later with circular polarization techniques in Canada (see section 5) and with differential reflectivity (Hall et al., 1980; Bringi et al., 1986a,b). Newell et al. (1955) also noted that the maximum reflectivity in the melting layer occurred at a height varying from 0 to 150 m above the height of the maximum cancellation. In addition to shape effects, they concluded that "partial preferred orientation sometimes occurs in the melting layer, but random orientation is the prevailing circumstance, certainly in rain, in which case our cancellation ratios are uniquely dependent on shape." These results were derived from measurements made in the winter using both horizontal and vertical polarizations and comparing the two returns as is done for differential reflectivity measurements. They also compared cancellation ratios and reflectivity levels ( $Z$ ) and concluded there was no dependence of cancellation ratio on reflectivity as might be expected from a consideration of drop shape and rainfall intensity. They were unable to conclude anything experimentally regarding hail, but did state that they anticipated "extreme cancellation ratios." Recent observations of differential reflectivity (Bringi and Hendry, Chapter 19a) and aircraft observations of raindrop shapes and orientation (Bringi et al., 1984) do not support Newell et al.'s conclusion that raindrops are randomly oriented, although Newell et al.'s relative linear polarization data on copolar returns in different regions of the cloud are comparable to differential reflectivity data now regularly measured with polarization radars.

Both the reports by Newell et al. and an earlier report by Atlas and Donaldson (1955) at the Air Force Cambridge Research Center (AFCRC) reflect a basic awareness of physical phenomena that are central to modern polarization diversity measurements; namely, the oblateness of raindrops and the irregular nonspherical shape of hailstones. The understanding at that time was that large, nonspherical hailstones would have a preferred orientation, with their larger dimensions horizontal, so that they would be indistinguishable from rain in measurements of the cancellation ratio, the circular depolarization ratio, or

the linear polarization differential reflectivity. Although the measurements of raindrop shape by Magono (1954) were cited by Newell et al. (1955, 1957) the relationship of size and shape appears not to have been fully appreciated by radar meteorologists (Barge, 1972; Seliga and Bringi, 1976) until it was measured with more precision by Pruppacher and Pitter (1971).

Bridges (1964) presented a survey of five radar remote sensing techniques to measure the particle drop-size distribution of water clouds and rain. Of particular interest is the technique of sidescattering in the Rayleigh and Mie regions. This bistatic approach has not received much attention in meteorology but is used in other fields, especially with the advent of laser techniques in the laboratory. For example, Kerker (1969) gave an extensive review of the theory and application of electromagnetic wave scattering for the determination of particle size distributions, focusing on problems of physical chemistry and including polarization principles. Bridges suggested that "for distributions having drops with about the same diameter, the diameter could be estimated by measuring the ratio of the vertically polarized component to the horizontally polarized component." He also suggested that the copolar ratio be combined with the sidescattered power at either polarization to deduce constants of two-parameter drop-size distributions, similar to the differential reflectivity backscatter concept of Seliga and Bringi (1976). The second technique of interest is based on polarization effects in the Rayleigh region. In this case Bridges suggested that the cancellation and reflectivity could be combined as the basis from which the two-point drop-size distribution of heavy rain could be determined. The larger diameter drops depart more from spherical conditions, and rain containing proportionally more of the larger drops can be identified by a measurement of greater cancellation ratios. Bridges believed that the results of Newell et al. (1957), discussed previously, indicated that this method might be feasible.

Atlas (1966) was issued a patent based on circular polarization principles for use in aircraft guidance in storms. This patent relied on transmitting right circular polarization and receiving alternately right and left circularly polarized waves. The measure of cancellation would then be used to aid in the detection and characterization of rain and ice hydrometeors. An attempt to implement this concept on the CPS-9 radar at AFCRC was inconclusive. Along with the measurements at MIT and others from that period, this effort suffered from deficiencies of available equipment. Dual-port antennas were not generally available for meteorological research, the polarization purity of antennas was not high, fast switching of transmitted polarizations was unrealized, and receiving systems did not permit real-time sampling and display of multiple parameters measured at multiple range gates.

Thus, in the late 1950s, there was little impetus in the United States for further meteorological research with polarization diversity radar techniques, despite the continuing

interests in hail detection and quantitative precipitation measurement. Radar meteorological research in the United States emphasized quantitative reflectivity measurements, interpretation of the structure of precipitation systems, the estimation of rainfall rate from reflectivity measurements, and, especially in the 1960s, the development of Doppler techniques.

Two other factors most likely also contributed to the lack of a strong interest in radar polarimetry in the United States during the 1960s. The advent of Sputnik in 1957 and the development and deployment of weather-observing satellite systems shortly thereafter caused a revolution in the atmospheric sciences. The first photographs of global weather systems provided new insights and posed new challenges to meteorologists, drawing much attention away from reliance on traditional observational systems including the developing radar meteorological remote sensing platforms. A second factor was the withdrawal of support for related research in the universities in the early 1960s by agencies of the Department of Defense. Established meteorological radar programs at MIT, McGill University, and the Illinois State Water Survey, as well as many other scientific and engineering research fields, lost base support. Not until the late 1960s and early 1970s did the National Science Foundation (NSF), through its Meteorology Research Program and the National Center for Atmospheric Research, begin to make up for the loss of national support in radar meteorology at the universities.

In the United States, only Louis Battan at the University of Arizona continued to investigate the polarization dependence of meteorological backscatter through the 1960s (Battan and Theiss, 1970). These measurements were limited to vertical incidence and included absolute reflectivity, linear depolarization ratio, and the Doppler spectrum of either of the received signals, but not both simultaneously. Battan continued this work into the 1970s. In the early 1970s, research on cloud physics and storm electrification by Marx Brook at New Mexico Institute of Mining and Technology led to the first simultaneous coherent reception of horizontally and vertically polarized signals. Signal spectra, spectral power ratios, and complex cross spectra computed from measurements made in 1975 were presented in several conferences but have never been formally published because of ambiguities in their physical interpretation. This effort was prematurely terminated when the radar at New Mexico Tech was struck by lightning; this radar has recently been restored to operational condition, with improved capability.

#### 4 EARLY SOVIET ACTIVITIES IN POLARIZATION RESEARCH

Soviet scientists were among the first to apply polarization radar techniques to meteorology. The majority of this work occurred in the 1950s and 1960s with the last radar conference paper appearing in 1975 in the Preprints of

the 16th Radar Meteorology Conference, Houston, Texas (American Meteorological Society). The history of polarization research followed the path of theory to set the framework, equipment developments, observations of clouds and precipitation, and then other specific applications such as weather modification.

Shupiatskii (1959) reported on calculations of polarization parameters resulting from radar scattering by nonspherical particles. The calculations are based on Gans's theory applied to ice and water ellipsoids. The results reported are similar to those of Atlas et al. (1953). Another theoretical study by Gershenson and Shupiatskii (1961) looked at scattering of elliptically polarized waves from nonspherical atmospheric particles. This appears to be the earliest mention in the Soviet literature on how to determine the phase state in a cloud. The work of Shupiatskii (1959) is the starting point in determining the cancellation ratio versus the shape factor; and he argued that since heavy rain is composed of deformed wet particles and hail is dry, hail should depolarize less.

These papers provided the framework for the interpretation of observational data. Shupiatskii and Morgunov (1963) described a polarization radar system consisting of two antennas and a single receiver. The use of a single receiver eliminated calibration problems and the difficulties of matching receivers. Observations of precipitation revealed that wet snow depolarized more than dry snow or rain and that the radar bright band depolarized more than rain or snow. They noted that the antenna became a limiting factor in some of the measurements. It would appear that the integrated cancellation ratio was of the order of  $-20$  to  $-25$  dB. Minervin and Shupiatskii (1963) also reported that for nonconvective clouds the depolarization was greater when ice or snow was present than when only rain was present.

In North America, one of the driving forces behind research in radar polarimetry was weather modification. This was also the case in the 1960s for Soviet scientists. Morgunov and Shupiatskii (1964) reported on the use of polarization techniques to evaluate cloud seeding experiments that were carried out during August 1961. Observations at 5 km height, prior to seeding, revealed depolarizations of  $-17$  to  $-19$  dB which were interpreted as scattering from liquid drops. After seeding, at 3 km height the values were  $-9$  to  $-10$  dB and at 5 km height they were  $-8$  to  $-12$  dB. The larger depolarizations were interpreted to be the result of ice crystals formed by the seeding agents. In other words, the radar was able to observe a phase change as a result of cloud seeding.

This small sampling of Soviet research is representative of the type of early radar polarimetry work carried out in the 1960s. The pattern of development is similar to that elsewhere, and, although equipment limitations are evident, these efforts helped to encourage others to pursue the development and application of radar polarimetry techniques to meteorology.

## 5 EARLY CANADIAN ACTIVITIES IN POLARIZATION RESEARCH

In Canada, the major advances in radar polarimetry followed two parallel paths based on technology developed at the National Research Council (NRC). Related fundamental work was done earlier by Kerker and Hitschfeld (1950) and Atlas et al. (1953). Initial work at NRC started in the late 1950s and early 1960s when the Radio and Electrical Engineering Division was involved in precipitation clutter suppression techniques for military radars and evaluation of the performance of a circularly polarized military radar during precipitation. In 1956 the Alberta Research Council (ARC) began a collaboration with NRC in Ottawa and McGill University in Montreal to study hailstorms in Alberta (Hitschfeld, 1971). The NRC installed a 3.2-cm Decca DC-19 radar in Penhold, Alberta in 1957 and replaced it with a 10-cm FPS-502 in 1963. Meanwhile, NRC was studying the characteristics of precipitation as a signal propagation medium. These studies led to the development of a polarization diversity 1.8-cm radar (McCormick, 1964; Hendry and McCormick, 1968; McCormick and Hendry, 1979), which was first operated in 1965. This development was spurred on by the recognition that investigations into clutter suppression and precipitation measurements using polarization techniques had been limited by the poor polarization quality of the antennas used (e.g., see Shupiatskii and Morgunov, 1963). Meanwhile, NRC was designing a dual polarization antenna for the FPS-502, using a feed horn that was scaled from the 1.8-cm feed horn. This antenna was installed in Alberta in the spring of 1967 (Allan et al., 1967); its goal was to detect hail in convective storms by means of the circular depolarization ratio and the cross-correlation of simultaneously received signals of right and left circular polarization (McCormick, 1968). The research efforts at both NRC and ARC were influenced by research in the Soviet Union, where polarization diversity radar measurements had been conducted in conjunction with weather modification programs as noted earlier (e.g., Gershunov and Shupiatskii, 1961; Minervin and Shupiatskii, 1965).

Canadian measurements of the circular depolarization ratio initially yielded ambiguous results, but within five or six years it became evident that the cross-correlation was a good discriminant of hail, because of the tendency of hailstones to be randomly oriented, contrary to the prevailing opinion in the 1950s. Progress continued to be hampered by limited capability for real-time display of the measured quantities; real-time display of the cross-correlation was implemented in 1972 (Hendry and Allan, 1973). The lack of early unambiguous results from either of the Canadian radars contributed to the resistance encountered by the 1975 proposal from Dr. T. A. Seliga at the Ohio State University to investigate the differential reflectivity technique.

From 1970 onward, results of measurements by ARC and NRC were presented in almost every conference on radar meteorology. The theory of dual circularly polarized measurements of precipitation developed by Dr. Glendon McCormick (1968) was incorporated into the doctoral theses of Dr. Brian Barge (1972) and Dr. Robert Humphries (1974) and ultimately published formally (McCormick and Hendry, 1975). Early results of measurements of the shapes and orientations of hydrometeors were published by McCormick et al. (1972), Hendry et al. (1976), and elsewhere in the literature of meteorology and electrical engineering.

By the mid-1970s, as a result of the studies at Ottawa and Alberta, it was concluded that rain tended to fall with its symmetry axis vertical and that the degree of correlation between the main and orthogonal components was higher for rain than for hail. Furthermore, it was thought that the circular depolarization ratio could help distinguish rain from hail, but propagation effects could not be ignored. A combination of the circular depolarization ratio, the radar reflectivity factor, and the cross-correlation was shown to be sensitive to the precipitation type and hence useful for the identification of the hydrometeors present.

The remarkable achievements in Canada resulted from the fortuitous combination there of all the elements necessary for productive scientific research: a firm purpose, competent people, good ideas, adequate financial resources, and strong technical support. According to McCormick, the antenna developments at NRC would have been impossible without "a good and patient machine shop."

## 6 OTHER EARLY CONTRIBUTIONS TO RADAR POLARIMETRY

Browne and Robinson (1952) most likely reported the first cross-polarization measurements of scattering from hydrometeors, focusing on the response in the melting layer with a vertically pointing radar. Hunter (1954), also at the Telecommunications Research Establishment (now Royal Signals and Radar Establishment) in England, reported on a 3.2-cm, obliquely pointing radar capable of receiving dual, circularly polarized signals. He reported orthogonal circular polarization measurements of various types of precipitation, including rainfall rates of various intensities, the melting band and fine snow. The results agreed fairly well with what was expected from theoretical considerations. More detailed information on these and other measurements at 8.6 mm were given later by Gent et al. (1963). (See Probert-Jones, Chapter 7, for a discussion of the early work in England.)

A decade later Hodson and Peter (1964) reported on observations made in South Africa. Their measurements supported the assumption that raindrops fall as oblate spheroids. They also observed that the cancellation from hail was greater than from rain; they presumed this was due to the different dielectric properties of hail, given a

similar shape. They further interpreted their cancellation measurements in terms of equivalent drop size by relating cancellation measurements to theoretical predictions based on the drop ellipticities of Best (1947). Measurements using Laws and Parsons's (1943) drop-size distributions predicted larger than expected rainfall rates. Hodson and Peter were clearly on the right track toward the discovery of how to use dual polarization measurements for recovering better estimates of rainfall characteristics.

## 7 BEGINNINGS OF THE MODERN ERA IN THE UNITED STATES

The modern era of meteorological research with polarization diversity radars in the United States can be traced to research conducted at The Ohio State University (OSU) beginning in 1973. The origin of this research constitutes an interesting interdisciplinary story. It was led by Dr. Thomas A. Seliga, who had joined the OSU faculty in 1969 as part of a recruitment effort to strengthen the University's research programs in the atmospheric sciences. His professional background was primarily in the propagation and scattering of radio waves in the ionosphere. As a graduate student and faculty member at The Pennsylvania State University, working in the Ionosphere Research Laboratory, he became knowledgeable about a technique of determining electron densities and collision frequencies in the D region from measurements of the small differential amplitude and differential phase of backscattered radio signals as the ionosphere is intermittently perturbed by a second radio transmitter. He was thus very familiar with polarization phenomena and with differential measurement techniques. While at the National Science Foundation in 1967-68 as Program Director for Aeronomy, Seliga was introduced to radar meteorology and became aware of the multiparameter problem of radar rainfall estimation.

The coincidence in 1972 of a lack of funding for continuation of Seliga's research in radio propagation in ionized media and the establishment at OSU of an interdisciplinary Atmospheric Sciences Program fortuitously provided the basis for Seliga to enter the field of radar meteorology and attack the long-standing problem of rainfall estimation. With V.N. Bringi, who entered OSU as a graduate student in 1972, Seliga considered the shapes of raindrops and hypothesized that it should be possible to measure the differential reflectivity of raindrops even if the distortion of the drops were small (Pruppacher and Pitter, 1971). Research results emerging from Canada tended to support this concept, as they showed that raindrops had a high degree of common orientation. The ensuing research, supported by OSU internal funds and by Bringi's University Corporation for Atmospheric Research (UCAR) fellowship, showed both the physical significance of the differential reflectivity and the feasibility of measuring it (Seliga

and Bringi, 1976). A key element of the theory was the use of radar measurements to determine both the coefficient and the exponent of a drop-size distribution. Within a few years, proof of concept measurements were reported both in the United States by Seliga et al. (1979) and in England by Hall et al. (1980).

Other efforts in polarization diversity radar research in the United States during the 1970s and early 1980s, such as the work of Seliga and Bringi (1978), Metcalf and Echard (1978), and Pasqualucci et al. (1983), were closely tied to theoretical and experimental developments in Canada. These are described further in Chapters 19a and 19b.

## 8 CONCLUSIONS

The authors recognize many other contributions to radar polarimetry from other countries and scientists, but this history is intended to focus on the early developments. Early progress in this field was limited both by capabilities of available equipment and by uncertainties in interpretation. More important, perhaps, was the fact that advances in polarimetry were overshadowed by other advances in radar meteorology, including the systematic integration of radar technology (power measurements) into studies of clouds and weather systems, and the introduction in the 1960s of Doppler measurements, which immediately began yielding new insights into storm dynamics. These measurements, however, were incomplete and did not adequately answer several of the most important questions, including whether accurate rainfall estimation and reliable hydrometeor phase discrimination are possible. Polarimetry, supplemented by advances in supporting technology, now appears to have produced major progress toward these ends, as suggested by the reviews of current developments by Bringi and Hendry (Chapter 19a), Metcalf (Chapter 19b) and Jameson and Johnson (Chapter 23a). Future prospects for research in the area are excellent, particularly if the many possible applications to be impacted by polarimetric radar measurements are considered; e.g., see Seliga (1980), Seliga et al. (1982), Hall (1984), Hendry and Antar (1984), and Leitao and Watson (1984). Fields potentially benefiting include hydrology, cloud physics, climatology, weather modification, communications, agriculture, and weather nowcasting.

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